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CALCIUM, MAGNESIUM, AND POTASSIUM UPTAKE BY CRESTED WHEATGRASS GROWN ON CALCAREOUS SOILS

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ABSTRACT: Forage intake with potassium/(calcium + magnesium) [K/(Mg + Ca)] values in excess of 2.2 are associated with grass tetany and Mg deficiencies in ruminants. This study was conducted to determine the degree to which forage K and Mg concentrations and K/(Ca + Mg) ratios could be predicted from soil bicarbonate (HCO_3) extractable phosphate-phosphorus (PO_4-P), and saturation extract Ca, Mg, K, sodium (Na), and nitrate-nitrogen (NO_3-N) concentrations. Crested wheatgrass (*Agropyron* spp) strains and cultivars representing four ploidy levels were grown in the greenhouse on eight calcareous soils with different saturation extract Ca, Mg, K and K/Mg ratios. The plants were harvested three times. Soil solution K/(Ca + Mg) and K/Mg ratios were the only measured soil parameters that showed a consistent correlation with plant K/(Ca + Mg) ratios. Bicarbonate extractable soil P was positively related to plant P and K uptake in the first harvest, but was not related in the second and third harvests nor was soil P related to plant Ca or Mg content. There was a tendency for the higher ploidy level entries to have higher plant K/(Ca + Mg) ratios. It was concluded that soil K/(Ca + Mg) ratios can be used to predict relative forage K/(Ca + Mg) ratios for grasses grown under similar conditions.

INTRODUCTION

Forage plants that contain very low Mg concentrations and/or have high K concentrations tend to promote Mg deficiencies (grass tetany) in ruminants. Grass tetany losses in the United States alone are currently estimated at \$150 to \$400 million annually (Grunes and Mayland, unpublished). This problem could be

It should be remembered that while K/Mg or K/(Ca + Mg) values may provide a measure of the grass tetany risk, there are other factors that also influence grass tetany potential in ruminants.

In southern Idaho, soils formed from mafic parent materials (high in Ca and Mg relative to K) exist adjacent to soils derived from felsic parent materials (high in K relative to Ca and Mg). It is not uncommon to find rangeland soils in this area where K accounts for 30 to 60 percent of the soluble cations at concentrations up to 30 mmol/L in saturation extracts (Robbins and Carter, 1983).

The purpose of this study was to determine the effect of native soil Ca, Mg, Na, and K concentrations and ratios on cation accumulation in crested wheatgrass (*Agropyron* spp.) and to determine the variation in cation composition among four crested wheatgrass strains and cultivars with different ploidy levels grown on eight calcareous soils.

MATERIALS AND METHODS

Soils

The eight soils used in this study (Table 1) were selected to provide a range and mix of Ca, Mg, and K concentrations, and K/(Ca + Mg) and K/Mg ratios in the saturation extracts (Table 2). Portneuf silt loam was derived primarily from mafic parent material loess and tends to be relatively higher in Mg than K when compared to the other soils used in this study. Marshdale loam was derived from a mix of mafic and felsic parent materials and formed in low lying flat areas that are cool and wet most of the year. The other four soils were derived primarily from felsic materials and tend to have higher K contents relative to Mg than the first two soils.

The Portneuf, Marshdale, Starhope, Bedke, and Freedom #1 soils had not previously been irrigated nor cultivated. The Declo soil had been irrigated for over 100 years with low EC (<0.3 dS/m) water. The Freedom #2 soil had been irrigated with 0.45 dS/m water for one barley (*Hordeum vulgare* L.) crop and the Freedom #3 soil had been irrigated for three alfalfa (*Medicago saliva* L.) cuttings with 1.3 dS/m water.

The initial soil ion concentrations and EC data reported in Table 2 were used to select the soils. The soils were air dried, sieved through a 2-mm screen, and thoroughly mixed. Saturation soil pastes were made and allowed to stand overnight. The paste pH was measured, and the saturation paste water content was

TABLE 1. Taxonomic Class and Predominate Parent Materials of the Soils Used.

Soil Series	Taxonomic class	Original parent material
Marshdale loam	Fine, loamy, mixed, frigid Cumulic Haplaquolls	Granite, andesite, rhyolite, and basalt
Starhope loam	Fine, montmorillonic, frigid Ultic Arixerolls	Andesite and rhyolite
Declo sandy loam	Coarse-loamy, mixed, mesic Calcic Haploxerolls	Welded tuff, andesite, and rhyolite alluvium
Bedke silt loam	Fine, loamy, mixed mesic Durixerollic Haplargids	Loess, andesite, and rhyolite alluvium
Portneuf silt loam	Coarse-silty, mixed, mesic Durixerollic Calciorthids	Loess deposits on basalt plains
Freedom silt loam #1	Fine-silty, mixed, mesic Xerollic Calciorthids	Andesite and rhyolite alluvium and colluvium
Freedom silt loam #2	Fine-silty, mixed, mesic Xerollic Calciorthids	Andesite, rhyolite alluvium, and colluvium
Freedom silt loam #3	Fine-silty, mixed, mesic Xerollic Calciorthids	Andesite, rhyolite alluvium and colluvium

determined gravimetrically. The pastes were then vacuum extracted and the EC and water soluble Ca, Mg, Na, K, and NO_3-N concentrations were determined on the extracts. Calcium and Mg were also extracted with 1.0 molar sodium acetate (pH = 8.2), and Na and K were extracted with 1.0 molar ammonium acetate (pH = 7.0). Exchangeable cations were calculated as the difference between the saturation paste extract and the acetate extractable concentrations. Calcium and Mg were determined by atomic absorption spectrophotometry, Na and K by flame emission spectrophotometry (Robbins and Wiegand, 1990), and NO_3-N by ion chromatography (Robbins 1989). Bicarbonate extractable P was determined by an ascorbic acid method (Watanabe and Olsen, 1965).

Plant Materials

Crested wheatgrass lines selected for this study were 'Fairway' (2X *Agropyron cristaturn* (L.) Gaertner), 'Nordan' [4X A. *desertorum* (Fisch. ex Link)], a pentaploid (5X) hybrid between 'Hycrest' (an induced tetraploid strain of *A. cristaturn* x *A. desertorum*) and a broad leafed hexaploid line (*A. cristatum*), and a 6X *A. cristatum* (L.) Gaertner.

TABLE 2. Soil Saturation Extract Ion Concentrations, Cation Ratios, and EC; Saturation Paste pH and Water Content; Water Extractable NO_3-N; and Bicarbonate Extractable PO_4-P, as Measured Before Cropping.

Soil series	Ca	Mg	Na	K	Cl	SO_4	HCO_3	$\frac{K}{(Ca+Mg)}$	K/Mg	EC	pH	Saturation	NO_3-N	PO_4-P
	m mol L^{-1}									dSm^{-1}		kg kg^{-1}	mg kg^{-1}	
Portneuf	2.4	1.0	0.3	0.9	1.3	0.3	8.3	0.52	0.9	0.8	7.9	0.42	7	13
Marshdale	4.3	1.3	8.3	0.4	2.7	1.1	8.9	0.14	0.3	1.2	7.1	0.78	62	47
Starhope	0.7	0.7	0.4	1.1	0.5	0.2	0.5	1.57	1.6	0.4	6.2	0.30	7	26
Declo	3.4	1.1	1.5	3.0	1.0	1.0	8.2	1.33	2.7	1.0	7.6	0.64	9	29
Bedke	2.4	1.0	0.6	0.9	0.6	0.2	5.7	0.53	0.9	0.8	7.7	0.34	10	14
Freedom 1	1.4	0.7	22.2	4.3	10.7	0.9	15.7	4.10	6.1	2.8	8.3	0.44	56	16
Freedom 2	6.8	3.4	16.4	2.9	1.8	4.7	6.7	0.57	0.8	3.1	7.6	0.44	83	31
Freedom 3	1.7	1.1	19.7	3.2	1.0	7.1	8.5	2.29	2.9	2.5	8.5	0.44	67	19

Greenhouse Study

The greenhouse pot study was conducted from 26 November to 4 April under natural lighting and the air temperature was maintained between 15 and 25°C. Crested wheatgrass was planted in 4.0-L plastic pots filled with 3.50 kg of air dry soil that had been passed through a 2.0-mm sieve. The soils were irrigated to half saturation water content (an estimation of field capacity, Table 2), allowed to stand over night and then planted (day 1). When the plants had grown to 20 to 30 mm in height (day 17), they were thinned to six plants per pot and the pots were placed in a circulating water bath maintained at 16°C and a water depth of 0.14 m. The pots were arranged as a completely randomized design of four crested wheatgrass entries, eight soils and three replications. Each pot was watered back to the original weight two times a week with distilled water. The pots were repositioned in the water bath each week by rotation at a rate that took 42 days for each pot to reach its original position. Ammonium nitrate fertilizer was applied at 25 μg N/gm of soil on days 41 and 64. Forage samples were harvested on 25 January, 4 March, and 4 April (days 60, 96, and 127, respectively).

Plant Analysis

The grass samples were oven dried at 60°C and then ground in a Wiley mill to pass a 40-mesh sieve. Subsamples were digested in 3:1 nitric:perchloric acid (HNO_3:$HClO_4$) and diluted with water to a uniform volume. Aliquots were diluted with 1 g lanthanum (La)/L as lanthanum chloride ($LaCl_2$) and analyzed for Mg and Ca by atomic absorption spectrophotometry, and for K by flame emission spectrophotometry. The remaining solution was analyzed for Na, manganese (Mn), iron (Fe), copper (Cu), and zinc (Zn) by atomic absorption spectrophotometry and colorimetrically for P using the vanadate-molybdate-yellow procedure.

Analytical accuracy and precision were determined by analyzing the National Institute of Standards and Technology SRM-1572 Citrus Leaf Standard with the grass samples. The recoveries were 88±1.6 Ca, 92±2.0 Mg, 95±1.6 K, 124±3.4 Na, 116±2.2 Cu, 98±1.8 Mn, 98±2.0 Fe, 99±1.1 Zn, and 100±3.2 P percent of the listed values. The K/(Ca + Mg) and K/Mg ratios in both plants and soils were calculated on the moles of charge basis.

RESULTS

Significant differences in Ca, Mg, K, Na, and P concentrations, K/(Ca + Mg) and K/Mg ratios, and yields were found across the four grass selections for the

TABLE 3. Mean Squares of Element Concentrations, Element Ratios, and Yield by Harvest.

Source	df	Mean squares							
		Ca	Mg	K	Na	P	K/(Ca+Mg)	K/Mg	Yield
		First harvest							
Soils	7	3.81**	1.53**	20.2**	11.6**	5.93**	0.32**	107.2**	5.63**
Ploidy	3	0.44	0.96**	150.3**	.53**	.24*	0.13**	14.3**	4.73**
Soil x ploidy	21	0.55**	0.03	3.1	.11*	.07	0.07**	2.2	0.40**
Error	64	0.19	0.03	3.8	.04	.06	0.02	1.6	0.11
		Second harvest							
Soils	7	24.12**	1.26**	355.1**	14.9**	3.08**	2.36**	84.0**	6.77**
Ploidy	3	6.23**	0.31**	53.6**	.22	.62*	0.59**	7.8	2.47**
Soil x ploidy	21	0.54	0.05	10.6*	.20	.40	0.06	4.3	0.29*
Error	64	0.33	0.04	6.1	.09	.19	0.04	3.0	0.15
		Third harvest							
Soils	7	22.08**	1.40**	332.7**	12.54**	3.48**	3.30**	120.4**	14.71**
Ploidy	3	4.32**	0.32**	203.7**	1.67**	.31	1.17**	13.0*	0.73**
Soils x ploidy	21	0.65*	0.07	9.1	.64**	.17	0.09*	7.4*	0.20**
Error	64	0.30	0.04	7.8	.22	.14	0.04	3.5	0.06

*,** Significant at $P < 0.05$ and $P < 0.01$, respectively.

three harvests due to soil differences (Table 3). Differences were also shown among grass selections in all cases, except Ca in the first harvest, Na in the second harvest, P in the third harvest, and the K/Mg ratio in the second harvest. Soil x grass selection interactions were found for Ca uptake in the first and third harvests, K concentration in the second harvest, Na in the first and third harvests, K/(Ca + Mg) ratio in the first, and third harvests, K/Mg in the third harvest, and yield in all harvests. There were significant differences in the plant K/(Ca + Mg) ratios due both to soils and plant selections for all three harvests. Soil x grass selection interactions for K/(Ca + Mg) were found in the first and third harvests but not in the second.

Grasses with higher ploidy levels tended to have higher Mg, K, and Na concentrations for all three harvests (Table 4). Calcium and P concentrations in the plants did not follow a definite pattern with ploidy level increases, nor was it consistent between harvests. The net result was that there was a mixed trend for the plant K/(Ca + Mg) to increase as the ploidy level increased. The K/Mg ratio and plant yield did not follow a consistent pattern from one harvest to the next across grass selections.

Correlations among plant and soil cation concentrations and ratios are shown in Table 5. Plant Na concentration was the only cation factor that was consistently correlated with soil Ca concentrations. Plant Mg concentration was the only cation that was consistently correlated with soil Mg concentration. Plant Ca and Na were consistently correlated with soil Na and K concentrations. Plant Ca and Na and the K/(Ca + Mg) ratio were strongly correlated with soil K, and K/(Ca + Mg) and K/Mg ratios for all three harvests.

Bicarbonate extractable PO_4-P concentrations varied from 13 to 47 mg P/kg in the eight calcareous soils and is considered more than adequate for grass growth. Yields and plant K concentrations were positively correlated with bicarbonate extractable PO_4-P levels for the first harvest only. Bicarbonate extractable PO_4-P was negatively correlated with plant Mg and positively correlated with K/Mg for the second harvest. There was not a significant correlation between PO_4-P and plant Ca or Mg concentration or Ca/P, K/(Ca + Mg), or K/Mg ratios for any of the harvests. These results are a reversal to the results of Reinbott and Blevins (1991) for winter wheat grown in low P, low pH systems.

Soil solution NO_3-N had correlation coefficients of 0.53, 0.59, and 0.65 for the three harvests, when compared with plant Mg concentration, however, there

TABLE 4. Least Square Means for Element Concentrations, Element Ratios, and Yield by Harvest, Across Soils.

Ploidy level	Ca	Mg	K	Na	P	K/(Ca+Mg)	K/Mg	Yield
	mg/g							g/pot
	First harvest							
Diploid	5.17ab	1.93b	38.1c	0.70c	3.7b	2.35c	20.2a	2.53a
Tetraploid	5.13ab	1.96b	39.8b	0.85b	3.8ab	2.46ab	20.9a	2.25b
Pentaploid	5.05b	2.26a	42.9a	0.91b	3.8ab	2.53a	19.5b	1.72c
Hexaploid	5.37a	2.31a	43.3a	1.06a	3.9a	2.44b	19.2b	1.58c
LSD (0.05)	0.25	0.09	1.1	.11	.1	0.08	0.7	0.19
	Second harvest							
Diploid	6.37b	2.15c	34.6b	0.81b	4.1b	1.85c	16.3ab	1.84c
Tetraploid	6.75a	2.27b	35.0b	0.95ab	4.3a	1.76c	15.7ab	1.81c
Pentaploid	5.80c	2.43a	36.9a	0.91ab	4.1ab	1.93b	15.4b	2.13b
Hexaploid	5.65c	2.30b	37.7a	1.04a	3.9b	2.11a	16.7a	2.50a
LSD (0.05)	0.33	0.11	1.4	0.18	0.2	0.12	1.0	0.22
	Third harvest							
Diploid	5.40a	1.83c	26.7b	0.52c	3.1	1.71b	15.0ab	1.88ab
Tetraploid	5.57a	1.95b	26.7b	0.71bc	3.1	1.66b	14.3b	2.00a
Pentaploid	4.72b	2.02ab	32.1a	0.91ab	3.3	2.10a	16.0a	1.85b
Hexaploid	4.81ab	2.10a	31.3a	1.13a	3.3	2.02a	15.4a	1.59c
LSD (0.05)	0.31	0.11	1.6	.27	.22	0.12	1.1	0.14

Values within each column for each harvest followed by the same letter are not significantly different at the 0.05 probability level. Each value is the mean of results for plant material from 24 pots.

TABLE 5. Linear Correlations (r)† among Plant and Soil Ca, Mg, Na, K, K/(Ca+Mg) and K/Mg Values.

Soil values	Harvests	Plant values Ca	Mg	Na	K	K/(Ca+Mg)	K/Mg
Ca	1	0.43	0.31	−0.38	ns	−0.48	ns
	2	ns	ns	−0.40	ns	ns	ns
	3	ns	ns	−0.35	0.29	ns	ns
Mg	1	0.31	0.46	ns	ns	−0.49	−0.42
	2	ns	0.35	ns	ns	ns	ns
	3	ns	0.34	ns	0.32	ns	ns
Na	1	−0.41	0.54	0.88	ns	ns	−0.64
	2	−0.71	0.43	0.82	0.53	0.67	ns
	3	−0.77	ns	0.69	0.55	0.79	0.35
K	1	−0.32	ns	0.71	ns	0.31	ns
	2	−0.46	ns	0.67	0.62	0.61	0.29
	3	−0.58	ns	0.60	0.45	0.70	0.57
K/(Ca+Mg)	1	−0.48	ns	0.85	ns	0.30	ns
	2	−0.54	ns	0.77	0.42	0.61	ns
	3	−0.63	ns	0.69	0.27	0.68	0.45
K/Mg	1	−0.42	ns	0.80	ns	0.27	ns
	2	−0.50	ns	0.73	0.48	0.61	0.31
	3	−0.59	ns	0.64	0.29	0.66	0.51

† Absolute values of r greater than 0.26 are significant at $P \geq 0.01$ and ns is not significant at the $P = 0.01$ level.

was not a correlation between soil NO_3-N, and Ca, Na, or K/(Ca + Mg) values. There was a soil NO_3-N correlation with plant K and K/Mg on the first and third harvests, respectively.

DISCUSSION

The ability to identify grass tetany prone grazing areas from surface geologic materials and soil cation concentrations and ratios would be useful in optimizing livestock production on Columbia Basin, Great Basin, and Northorn Rocky Mountian range lands. Some success has been achieved in predicting K/Mg and Ca/(Ca + Mg) ratios in forage grasses in other areas. The Bouldin model describes these relations for grasses grown in acid to neutral systems (Bouldin, 1989). This approach has not previously been considered for grasses grown on calcareous soils with adequate available P.

This study was conducted on the premise that felsic parent materials would give rise to soils and forage grasses with higher K/Mg and K/(Ca + Mg) ratios than mafic parent materials under arid and semi arid conditions. This is caused by the dominance of K and Na minerals in felsic formations, and the dominance of Ca and Mg minerals in mafic formations.

The most useful results of this study were the high and consistent correlations among the soil K, K/(Ca + Mg), and K/Mg ratios and the plant K/(Ca + Mg) ratios, and their consistent negative correlation with plant Ca concentrations. Soil Mg was also correlated with plant Mg concentration. Soil Mg was the only factor studied that was not correlated with plant Na. Under these conditions, there was not a consistent correlation between any of the soil factors tested and plant K/Mg ratio.

There appears to be a trend for the crested wheatgrass with higher ploidy levels to have higher K/(Ca + Mg) ratios when grown under these conditions. Other studies have shown genetic variability with respect to Ca, Mg, and K uptake within a given wheatgrass species (Mayland and Asay, 1989).

Studies on low available P and acid to neutral soils have suggested that increasing soil solution P levels would decrease the K/(Ca + Mg) ratio in grasses (Reinbott and Blevins, 1991), however under the conditions of this study on basic calcareous soils with adequate P, there was no correlation between available soil P and the cation uptake rates except for K in the first cutting, which would tend to raise the K/(Ca + Mg) ratio, had other factors remained constant.

The results suggest that these comparisons should be further tested in the field under natural conditions to determine if soil K/(Ca + Mg) or K/Mg ratios can be used to predict trends in plant K/(Ca + Mg) ratios grown on different soils under similar weather conditions.

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